SYNOPSIS OF RESEARCH PROJECT

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4.	**Name of Degree Submitted for**	:	Ph.D.
5.	**Major Subject**	:	SOIL AND WATER CONSERVATION ENGINEERING
6.	**Minor Subject**	:	IRRIGATION AND DRAINAGE ENGINEERING
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8.	**Title of the Research Project**	**:**	Development of Crop Water Stress Index and Crop Coefficient For Irrigation Scheduling of Summer Groundnut in a Semi-Arid Region

9. Introduction

agriculture worldwide is water shortage, which is being made worse by the growing effects of climate change (Hakami and Babazadeh, 2025). Rising temperatures, erratic rainfall patterns, and shifting hydrological cycles are significantly reducing the availability and reliability of water resources, putting agricultural productivity and long-term sustainability under risk (Kim et al., 2026). These challenges are particularly severe in semi-arid regions, where limited and highly variable precipitation directly influences soil moisture dynamics and crop water requirements. climate change is increasing evapotranspiration demand and irrigation requirements, further aggravating water stress in agriculture (Kumar et al., 2025 and Singh et al., 2026). Furthermore, rising temperature trends and rainfall unpredictability are expected to widen the gap between crop demand and water availability, emphasizing the crucial importance of proper irrigation management and climate-resilient agricultural practices (Patel et al., 2025).

Despite occupying only about 20% of the world's cultivated land, agricultural irrigation contributes more than 40% of global food production, highlighting its important in ensuring food security (World Bank, 2022; El-Shafei and Mattar, 2022). However, this heavy dependence on irrigation is placing immense pressure on freshwater resources. Globally, irrigation accounts for more than 70% of total freshwater withdrawals, and increasing competition among agricultural, industrial, and domestic sectors is expected to further limit water availability for farming (Su and Singh, 2024). In India, agriculture is the dominant land use, with a substantial proportion of the total geographical area under cultivation and a cropping intensity exceeding 150%. Irrigation fulfils a major share of agricultural water demand, yet it is largely dependent on groundwater resources, being extracted at unsustainable rates. Over-exploitation of groundwater results in declining water tables and reduced aquifer recharge, raising serious concerns about the future of irrigated agriculture.

This region characterized by semi-arid climatic conditions, the challenges of water scarcity are even more pronounced. High evapotranspiration rates, low and erratic rainfall, and increasing frequency of drought events necessitate the adoption of efficient irrigation management strategies. Traditional irrigation practices, particularly flood irrigation, often result water losses through evaporation, runoff, and percolation. Although micro-irrigation systems such as drip irrigation offer improved water use efficiency, their effectiveness depends largely on precise irrigation scheduling based on accurate estimation of crop water requirements. adequate irrigation techniques and excessive groundwater extraction are endangering agricultural productivity in Gujarat's semi-arid regions. Conventional flood irrigation, although widely practiced due to its simplicity and low initial cost, is associated with substantial water losses through deep percolation, evaporation, and non-uniform distribution. In contrast, drip irrigation systems offer higher water use efficiency but require optimized scheduling to realize their full potential under field conditions. The present study, which evaluates stress-based irrigation scheduling under deficit conditions using both flood and drip irrigation methods, is highly justified from a practical standpoint for providing a scientific comparison between flood and drip irrigation under identical deficit levels, helping to quantify differences in water savings, crop response, and efficiency. This is crucial for guiding farmers in selecting appropriate irrigation methods based on resource availability.

Estimating crop evapotranspiration (ETc), which is typically calculated using crop coefficient (Kc) methodologies, is a critical component of irrigation planning. The single crop coefficient (Kc) method simplifies water needs prediction by integrating soil evaporation and crop transpiration into a single parameter. However, in instances of climate unpredictability and deficit irrigation, this technique may fail to capture all of the dynamic interactions between soil, plant, and atmosphere. The dual crop coefficient technique provides a more comprehensive and physically realistic description of agricultural water use processes by dividing evapotranspiration into two coefficients: base crop coefficient (Kcb), which represents plant transpiration, and soil evaporation coefficient.

Local climate variability, soil characteristics, crop management approaches, and stress conditions are typically disregarded when applying generalized crop coefficient values, such as those proposed by standard standards. These distinctions become more evident as climate conditions change, resulting in inaccurate evapotranspiration estimations and suboptimal irrigation scheduling. Developing region-specific single and dual crop coefficients that appropriately depict field conditions is thus critical, particularly in stress-based and deficit irrigation regimes.

In this context, the development and evaluation of stress-based irrigation scheduling using crop coefficient approaches assumes significant importance. Such an approach enables more accurate estimation of crop water requirements, improves irrigation efficiency, and supports sustainable water management practices. By incorporating crop responses under varying moisture stress conditions, it also provides a realistic framework for optimizing water use without significantly compromising yield. Furthermore, the integration of region-specific crop coefficients with modern irrigation systems, such as drip irrigation, has the ability to significantly improve water productivity and reduce losses.

This is especially important in light of climate change, as precise and flexible irrigatio n systems are necessary to mitigate the risks of water scarcity and ensure continuous crop pro duction.Development of climate-responsive, region-specific crop coefficients represents a crucial step toward achieving efficient irrigation management, improving water productivity, and enhancing the resilience of agricultural systems. This study is therefore aimed at addressing these challenges by generating scientifically robust data and developing practical irrigation scheduling frameworks suitable for semi-arid regions.

9.1 Deficit Irrigation Scheduling

Deficit irrigation has more well-known as a viable water-saving technique in water-scarce. This strategy attempts to improve water-use efficiency (WUE) without significantly reducing yield by applying water below full crop-water requirements (Nikolaou et al., 2020; Abdelfattah and Mostafa, 2024). However, the effectiveness of deficit irrigation depends on crop type, critical growth stages, soil properties, and prevailing climatic conditions (Meena et al., 2019). Advanced irrigation scheduling techniques-such as soil-water balance models and soil moisture sensors ensure potential for improving precision but face challenges including high costs, site-specific calibration requirements, and limited sampling scales (Zotarelli et al., 2013). Plant-based sensing techniques, which directly record crop physiological reactions to water stress rather than depending only on soil or atmospheric data, have drawn more interest in an effort to get beyond these restrictions. Stress Degree Days (SDD), Crop Water Stress Index (CWSI), Water Deficit Index (WDI), and Canopy Temperature Variability (CTV) in directing irrigation management (Kumari et al., 2024). Among these, CWSI has emerged as one of the most reliable, economical, and non-destructive tools for quantifying plant water stress. Based on canopy-air temperature differentials (T_c–T_a), CWSI provides a dynamic measure of crop water and agro-climatic conditions (Yadav et al., 2024; Workneh et al., 2024). CWSI supports increased water productivity and resilience in agricultural systems by facilitating real-time monitoring of plant responses under fluctuating water supply in addition to providing precise irrigation scheduling(Gontia and Tiwari, 2008; Mali et al., 2025).

9.2 Crop Coefficient (K_c) Approach

The single crop coefficient (K_c) approach is a well-established method for estimating crop evapotranspiration (ET_c) in irrigation water management and planning. single coefficient (K_c), which is multiplied with reference evapotranspiration (ET_o) to derive ET_c. The method is extensively recommended in standard guidelines such as those provided by the FAO-56 framework. The single K_c approach is particularly suitable under conditions where crops are grown in well-watered environments with uniform soil moisture distribution and optimal agronomic practices. It provides a practical and efficient tool for irrigation scheduling at regional and large-scale levels, where detailed field-level data may not be readily available. their dynamic and independent responses to variations in soil moisture, climatic conditions, and irrigation practices have significant role.

10. Practical Utility of the Research Problem

Deficit irrigation is increasingly recognized as a viable approach to manage limited water resources. However, its success depends on precise scheduling and crop response understanding. This research will identify optimal deficit levels for both irrigation methods drip and flood, ensuring maximum yield with minimum water use using a locally estimated CWSI and crop coefficient. The CWSI is a helpful and reliable for studying crop water stress in real time based on canopy temperature, allowing for proper irrigation scheduling. This non-destructive, non-contact, and cost-effective method is suited for field applications since it employs infrared thermometry without causing crop damage. CWSI helps farmers determine the real timing and amount of irrigation, avoiding over- and under-irrigation and improving water-use efficiency, especially under deficit irrigation conditions. In the context of climate change, it supports adaptive irrigation management by providing continuous feedback on crop stress. Additionally, CWSI can be integrated with remote sensing and automated irrigation systems, promoting smart agricultural practices.

Locally developed crop coefficients provide significant utility under changing climatic conditions, especially in semi-arid regions like Gujarat where variability in temperature, rainfall, and evapotranspiration affects water management. These locally developed coefficients improve the accuracy of evapotranspiration estimation and enable climate-responsive irrigation scheduling under both drip and flood systems. They help farmers optimize irrigation timing and quantity, maintain yields under limited water supply, useful for input parameters in automated irrigation systems for real-time control and improved water-use efficiency. This approach promotes sustainable water management, enhances crop resilience, and overcomes the limitations of generalized crop coefficients under variable climate conditions.

By integrating stress-based irrigation with efficient delivery systems, the study will improve water productivity (output per unit of water). This is particularly important in semi-arid regions where every drop of water must be utilized efficiently. The inclusion of techno-economic study of the additional investment in drip irrigation is justified compared to flood irrigation under deficit conditions. This directly supports farmer-level decision-making in irrigation scheduling under different stress condition

The study promotes the adoption of deficit irrigation, particularly irrigation systems, Both CWSI and crop coefficient developed under local conditions, serve as highly effective inputs for modern automated irrigation systems. The crop coefficient can be used as a key input

parameter to estimate crop water requirement, while temperature sensors can continuously monitor canopy temperature to compute real-time CWSI values. When the CWSI reaches a predefined threshold (e.g., Management Allowable Depletion level),

This integration enables smart, real-time irrigation scheduling, improving water-use efficiency, reducing wastage, and maintaining optimal crop growth under stress conditions. Such an approach is particularly valuable under climate variability, as it combines plant-based stress detection with accurate crop water estimation, leading to sustainable and efficient irrigation management. This research bridges the gap between traditional irrigation practices and modern water-saving technologies, providing a scientifically validated, economically viable, and practically implementable irrigation strategy for enhancing water productivity and sustainability in semi-arid agriculture.

11. Objectives

1. To develop crop water stress index (CWSI) for the summer groundnut crop grown in semi-arid region
2. To assess the effect of stress-based irrigation scheduling on growth parameters and yield attributes
3. To develop a crop coefficient for the region
4. To evaluate the techno-economic feasibility of stress-based irrigation system

12. Review of literature

12. Review of literature

Ghamarnia et al. (2014) done an experiment at west Iran, the crop coefficient and crop water need of black cumin (Nigella sativa L.) were determined under semi-arid conditions during 2010-2011. The experiments were carried out using drainable lysimeters for two years, with silty clay soil and daily meteorological data collected from a nearby weather station. Reference evapotranspiration was estimated using the FAO-Penman–Monteith method, and both (K_c and K_{cb}) were calculated for initial, development, mid, and late growth stages. The water requirement of black cumin was 724 mm, with single K_c values of 0.59, 0.91, 1.29, and 0.78, and base crop coefficients (K_{cb}) of 0.24, 0.71, 1.09, and 0.78 for the respective growth stages. Total dry matter production was 9.48 kg/ha per mm of irrigation water, seed yield was 3.10 kg/ha per mm, reached 31%. Result shows dual crop coefficients provided more precise estimations of crop water requirements than single coefficients. The study recommends the use of these first-time derived K_c and K_{cb} values for black cumin in semi-arid regions and highlights the need to determine single and dual crop coefficients for other medicinal crops under varying climatic conditions to optimize water management and irrigation scheduling.

***Ghamarnia and Sasani (2015*)** conducted an experiment in the western regions of Iran, researchers used the SIMDualK_c model to simulate irrigation scheduling and estimate daily crop evapotranspiration (ET_c) of coriander (Coriandrum sativum L.) over two years using the dual crop coefficient approach. The model computes separate soil water balances for the soil evaporation layer to derive K_e and for the entire root zone to adjust K_{cb} according to soil moisture conditions. Lysimetric measurements of ET_c were used for model calibration and validation. The crop coefficients (K_{cb}) were determined as 0.21 for the initial stage, 1.12 for mid-season, and 0.79 at harvest. Model performance showed strong agreement with lysimeter measurements, with RMSE values of 1.64 mm and 1.53 mm for calibration and validation, modeling efficiency (EF) of 0.8, and index of agreement (dIA) of 0.93. Average modeled soil evaporation contributed 25% of ETc (181 mm). The study concluded that the SIMDualK_c model effectively simulates daily ETc for coriander under dual Kc methodology, providing a reliable tool for irrigation management and water resource planning in semi-arid regions.

Pandey (2016) conducted a study in the middle Gujarat region at Anand Agricultural University estimated crop water requirements (ET_c) for ten major crops—rice, wheat, maize,

pearl millet, chickpea, green gram, soybean, groundnut, mustard, and cotton—using twenty years (1993-2013) of meteorological data from Anand. Daily reference evapotranspiration (ET_o) was calculated via the FAO Penman-Monteith method, and stage-wise crop coefficients (K_c) adjusted for daily climatic variations were applied to estimate daily ET_c. Results showed ET_o peaked at 10.1 mm/day in late May and was lowest (4.0 mm/day) at year-end. Among crops, summer crops like groundnut (849.0 mm) and cotton (848.0 mm) had the highest ET_c, whereas winter crops like mustard (411.7 mm) had the lowest. ET_c varied with crop type, growth stage, season, and duration, increasing during development and mid-season and decreasing at maturation. The study recommends using these crop- and season-specific ET_c estimates to schedule irrigation efficiently, optimize and support crop production in the conditions of middle Gujarat.

Veysi et al. (2017) A study conducted at ICAR-Indian Agricultural Research Institute evaluated the use of remote sensing for estimating (ET_c) and (CWSI) in soybean under semi-arid conditions during 2016–17. The methodology involved the use of MODIS-derived Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) (K_c) and CWSI, while reference evapotranspiration (ET_o) was computed using the FAO Penman-Monteith model; lysimeter data were used for validation. Results indicated that seasonal ET_c was 304.4 mm (remote sensing) and 349.5 mm (lysimeter), with good agreement (R^2 = 0.86) and acceptable error statistics (RMSE = 0.66 mm/day). The study found that crop water stress was minimal during initial to mid-growth stages but increased during the late stage, as reflected by rising CWSI values (0.10-0.23). It also showed that remote sensing slightly underestimated ET_c but effectively captured crop water dynamics. Therefore, the study recommends the use of remote sensing-based ET_c and CWSI as reliable tools at both field and regional scales, enabling efficient water use with reduced labor, time, and cost.

Srinivas and Tiwari (2018) carried out a study utilizing lysimeters IIT Kharagpur (Precision Farming Development Center) to assess the seasonal water needs of green gram and its crop coefficient (K_c) during the Kharif season in sandy loam soil. This experiment employed three non-weighing lysimeters (1 m × 1 m × 1.2 m) to calculate daily crop evapotranspiration (ET_c) using a soil water balance method, while reference evapotranspiration (ET_o) was determined through DSS-ET version 4.1 depend on the FAO Penman-Monteith equation. The results shows that the ETc values at different growth stages were 36.83 mm (initial), 86.78 mm (crop

development), 67.12 mm (mid-season), and 16.52 mm (late season), indicating the highest water requirement during the development phase. The K_c values increased progressively from the initial stage (0.34) to the peak mid-season (up to 1.13), then declined towards maturity (0.17), which reflects the dynamics of crop growth. Parameters related to growth, such as plant height and branching, peaked during the mid-season, while the number of fruits rose from 16 (mid-stage) to 25 (late stage), with the maximum dry weight of fruit reaching 8.12 g per plant. The research identified discrepancies between the observed K_c values and the standard FAO values, indicating the significant impact of local climatic conditions and crop varieties. Consequently, it is advisable to establish location-specific K_c values for better irrigation management and water conservation, particularly in diverse agro-climatic scenarios.

Carvalho et al. (2018) examine a study Brazil, to estimate onion (Allium cepa L.) crop coefficients (K_c) under organic cultivation with and without elephant grass mulch, to find the effects of varying irrigation depths on yield and bulb quality in a Red Yellow Argisol with sandy loam texture. The experiment used a randomized block design in split plots with 10 treatments and seven replicates, and irrigation was managed using soil water balance and Time Domain Reflectometry probes at 7.5 and 22.5 cm depths. The crop coefficient values for onion without mulch were 1.0, 0.8, 1.0, and 0.8 for initial, development, mid-season, and late-season stages, respectively, while with mulch they were 1.0, 0.6, 1.0, and 0.7. Results showed that mulching reduced water use, lowering K_c by 18% in stage II and 3% in stage III compared to unmulched crops, while irrigation depth influenced yield and bulb size distribution. Marketable yields under mulched conditions reached 42 t ha^{-1} with 41.1% less water (207 mm) than uncovered soil, and higher irrigation depths increased larger bulb classes (C_4 and C_5). The study recommends integrating mulch with optimized irrigation scheduling to conserve water, maintain high yields, and improve bulb quality in semi-tropical onion production systems.

Prajapati and Subbaiah (2021) conducted two-year study at Junagadh Agricultural University evaluated crop coefficient (K_c) and evapotranspiration (ET_c) of Bt cotton under different mulching and irrigation regimes on sandy loam soil. The experiment used a split-plot design with three mulches (silver black plastic, biodegradable plastic, wheat straw) and a control, along with two irrigation levels (1.0 and 0.8 IW/ET_c), and ET_c was estimated using soil moisture sensors. Results showed that FAO-adjusted Kc values overestimated crop water requirements, causing water losses of 78.1 mm and 66.5 mm. Silver black plastic mulch recorded significantly lower K_c values across all growth stages compared to other treatments. The study also observed variation in K_c across years and treatments, highlighting the effect of

mulch and irrigation levels. It is recommended to avoid direct use of FAO K_c values under mulched conditions. Instead, sensor-based, location-specific Kc values should be adopted for efficient irrigation scheduling and improved water use efficiency.

Vadalia et al. (2022) done the research on a field study at Junagadh Agricultural University to evaluate stage-wise crop coefficient (K_c) and crop evapotranspiration (ET_c) of wheat (GW-366) under sandy loam soil during the Rabi season. The practical was done by using two land configurations-broad bed furrow (BBF) and flat land and two irrigation levels (1.0 ET_c and 0.8 ET_c), with soil moisture sensors used to estimate actual crop evapotranspiration and develop sensor-based K_c values. Results indicated that FAO-adjusted K_c values overestimated crop water requirements compared to sensor-based K_c, leading to excess water losses of about 106.18 mm (flat land) and 89.43 mm (BBF). The BBF system showed consistently lower K_c values than flat land due to better canopy structure and reduced evaporation losses. The study also found significant variation in K_c across growth stages, emphasising the irrigation level on crop water use.

Kumar and Rank (2023) conducted a study at the Instructional Farm of College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, to determine crop evapotranspiration (ET_c) and crop coefficients (K_c) of coriander using a Portable Automatic Closed Canopy Chamber (PACCC), Micro-Lysimeter (MLs), and field water balance (FWB) methods. The study area has a subtropical semi-arid climate with average annual rainfall of 1000 mm and pan evaporation of 2344 mm. Results showed no significant differences between ET_c measured inside and outside the PACCC or among PACCC, MLs, and FWB methods, indicating that short-term changes in microclimate (2 minutes) do not affect plant physiological processes. Stage-wise K_c values measured by MLs ranged from 0.66 (initial) to 1.26 (mid) and 0.98 (late), while FWB measurements were 0.67, 1.28, and 0.96 for initial, mid, and late stages, respectively. The study demonstrated that PACCC is a portable, cost-effective, and reasonably accurate tool for field measurement of ET_c and K_c, with actual crop evapotranspiration estimable as 1.185 times the PACCC-measured ET_c. The authors recommend using PACCC for practical field applications in irrigation scheduling and precise water management for coriander crops under semi-arid conditions.

Rajput et al. (2024) A two-year field investigation conducted at the ICAR-Indian ARS, New Delhi, evaluated crop evapotranspiration (ET_c) and developed single (K_c) and (K_{cb} and K_e) for broccoli under semi-arid climatic conditions during Rabi 2016–17 and 2017–18. The study

employed a weighing type field lysimeter to directly measure crop water use, while meteorological data were used to support evapotranspiration estimation. The results revealed that seasonal ET_c was 149 mm and 144 mm for the respective years, indicating consistent crop water demand across seasons. The single crop coefficient (K_c) values ranged from 0.67-0.68 (initial stage), 0.82-0.84 (development stage), 1.03-1.04 (mid-season), and 0.93-0.94 (late season), while the dual crop coefficient approach showed basal crop coefficient (K_{cb}) values of 0.30–0.98 and (K_e) values ranging from 0.18-0.42 across growth stages. The transpiration-to-ETc ratio (T/ET_c) of 0.73 indicated that crop transpiration contributed significantly (73%) to total evapotranspiration, with only 27% attributed to soil evaporation. The study shows that the developed K_c values were less than standard FAO recommendations, it is recommended to adopt region-specific accurate irrigation scheduling, improved water productivity, cost efficiency and provide high-resolution data for better irrigation management and decision-making.

Ramos et al. (2024) carried a global review of 58 studies to analyzed the effects of mulching on soil evaporation (E_s), crop coefficient (K_c), and actual evapotranspiration (ET_c act) across various crops and regions using a systematic comparison of mulched versus non-mulched conditions; results showed that mulching significantly reduces E_s and K_c, particularly during early growth stages, with plastic mulch (especially black film) although its impact diminishes as crop canopy develops, while inconsistencies in reporting mulch characteristics created variability in findings; therefore, the study recommends standardized experimental reporting and adoption of crop- and stage-specific mulching practices to improve efficiency without causing crop water stress.

Li et al. (2024) conducted a quantitative analysis of deficit irrigation optimize yield while conserving water in North China. They found that the, a strategy of 50% deficit irrigation led to a yield reduction of less than 5% compared to full irrigation, resulting in water savings of 1000–1100 m^3/ha and achieving high water productivity. They also observed that a 25% deficit irrigation approach maintained over 96% of the maximum yield while conserving 650-800 m^3/ha of water.

Sharma et al. (2024) conducted a experiment at Lovely Professional University during 2022-23 and 2023-24 developed growth-stage-specific crop coefficient (K_c) values for drip-irrigated wheat (Triticum aestivum, Cv. Unnat PBW-550) to account for local climate, soil, and water management conditions. The experiment used 24 drip-irrigated and 4 flood-irrigated

plots with irrigation applied at 50% soil field capacity, monitored via soil moisture sensors, and water volume measured with water meters. Stage-wise K_c values of 0.36, 0.77, 1.05, 0.69, and 0.25 were determined for initial, development, mid, late, and end stages, respectively, and crop evapotranspiration (ET_c) was estimated through water balance. Results showed that applying these tailored Kc values under drip irrigation increased grain yield by 36 (IWUE) threefold, and reduced water consumption by 61% compared to conventional flood irrigation. The study recommends using region and stage-specific K_c values for precise irrigation scheduling, sustainable wheat production.

Mali et al. (2025) conducted a study at Queensland, Australia, to assess spatial and temporal variations in crop water stress levels using UAVs equipped with multispectral and thermal sensors. The study calculated the (CWSI) using canopy temperature, air temperature, and vapor pressure deficit (VPD), and developed six machine learning models-LM, RF, DT, SVM, XGB, and ANN. using vegetation indices selected through along with thermal data for pre-heading, post-heading, and seasonal datasets. Results showed that seasonal models outperformed stage-specific models, giving the best performance (R^2 = 0.87, 0.82, and 0.93; RMSE = 0.09, 0.05, and 0.06 for seasonal, pre-heading, and post-heading datasets, respectively). SHAP analysis identified Red Normalized Value (RNV), thermal band data, and Green Red Vegetation Index (GRVI) as key predictors of CWSI, and generated maps effectively captured field-level variability in crop water stress. The study recommends integrating UAV-based RS with machine learning models for accurate, real-time monitoring of crop water stress and improving precision practices.

Colak (2026) conducted a field study at the Alata Horticultural Research Institute during 2019–2020 evaluated the (CWSI). The experiment included surface drip (DI), subsurface drip (SDI), and conventional flooding (CF) Class A pan evaporation, while canopy temperature was measured using an infrared thermometer to derive CWSI through T_c-T_a and vapor pressure deficit (VPD) relationships. Results showed that seasonal average CWSI ranged from 0.09 (CF) to 0.34 (SDI-I1.00), and a threshold value of around 0.15 was found optimal for drip irrigation to achieve water savings without yield loss. Surface drip irrigation at higher irrigation level (I1.50) provided better water productivity and yield compared to other drip treatments, while conventional flooding, though yielding higher output, was less sustainable due to excessive water use. The study also revealed a strong negative relationship between CWSI and yield as well as quality parameters, confirming its effectiveness as a water stress indicator. It is recommended to adopt CWSI-based irrigation scheduling using infrared thermometry and

integrate such thresholds into decision support systems for improving water use efficiency and sustainable rice production under water-scarce Mediterranean conditions.

13. Materials and Methods

This chapter outlines the research project planning, materials used, and the methodologies and techniques applied in conducting the study.

13.2 Study area

13.2.1 Location

The study area is situated at a latitude of 21° 29′ 03″N and a longitude of 70° 36′ 20″E, perched at an elevation of 64.32 meters above mean sea level. This location is approximately 3.5 kilometers to the south-west of the bustling town of Junagadh. It lies within the South Saurashtra Agroclimatic Zone of Gujarat State, an area characterized by its distinct agricultural potential and climatic conditions, contributing to the rich biodiversity and cultivation practices of the region.

13.2.2 Climate

The district is located in agroclimatic zones VII (North Saurashtra) and VI (South Saurashtra). The district has a medium to fairly hot climate all year round, with the exception of winter. The coastal belt experiences a humid climate, with low temperatures of 10 degrees Celsius in January and maximum temperatures of 42 degrees Celsius in May. From June to September. The last three years have seen an average of 559 mm of rainfall.

13.3 Experimental Layout

Field experiments will be designed and established under varying irrigation stress levels using both drip and flood irrigation systems to evaluate crop response under various water level. A large plot technique will be adopted with 4 replications irrigation system. The irrigation treatments will include full irrigation (no deficiency), 20% deficit irrigation and 40% deficit irrigation in different levels of water stress.

Factors:

- Irrigation Types (Factor A): I - Drip (I_1), Flood (I_2)
- Irrigation Regimes (Factor B):

  P - Full irrigation (P_1), 20% deficit (P_2), 40% deficit (P_3)
- Replications: 4

Table 1 Details of various treatment combination

DRIP		FLOOD	
T_1	I_1P_1	T_4	I_2P_1
T_2	I_1P_2	T_5	I_2P_2
T_3	I_1P_3	T_6	I_2P_3

Table 2 Field layout arrangement

	T_3	T_5	T_1	T_4	T_6	T_2
R_1						
R_2						
R_3						
R_4						

13.4 Data Collection

Meteorological and field data will be systematically collected over the crop period to support accurate estimation of crop water use and irrigation scheduling. Meteorological parameters including air temperature, relative humidity, wind speed height, and solar radiation will be recorded daily from weather station near the experimental site. Soil moisture content will be measured at 15cm soil depths using a soil moisture probe at regular intervals to monitor water availability in the root zone. Canopy temperature will be captures using an infrared sensor to assess plant water stress.

13.5 Measurement of Crop Growth and Yield Parameters

Growth and yield parameters of groundnut will be recorded in various stress level for both drip and flood irrigation systems across all replications. Canopy spread, plant height,

number of primary branches, and nodules will be measured from pre-tagged plants at appropriate growth stages.The total number of pods per plant, the number of seeds per pod, the hundred seed weight, the pod yield, and the shelling percentage will all be determined using standard procedures. Biological yield and harvest index will also be calculated to assess crop productivity under varying irrigation conditions.

13.6 Estimation of Reference Evapotranspiration

Reference evapotranspiration (ET_o) will be estimated using the FAO Penman–Monteith method. It accounts for both energy balance and aerodynamic factors.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where,

ET_0 = Reference evapotranspiration [mm day^{-1}]

U_2 = Wind speed at 2 m height [m s^{-1}]

R_n= Net radiation at crop surface [MJ m^{-2} day $^{-1}$]

G= Soil heat flux density [MJ m^{-2} day $^{-1}$]

T= Mean daily air temperature at 2 m height [°C]

γ = Psychrometric constant [kPa °C^{-1}]

Δ= Slope of vapour pressure curve [kPa °C^{-1}]

e_s - e_a= Saturation vapour pressure deficit [kPa]

13.7 Estimation of CWSI

Canopy temperature (Tc) was measured using a handheld infrared thermometer at a 30–40° angle from four corners of each plot between 12:00–14:00 under clear skies, from air temperature and relative humidity, while soil moisture up to 15 cm depth was monitored using the soil moisture sensor. CWSI was computed following the semi-empirical method of using lower and upper baselines of Tc–Ta for non-stressed and fully stressed conditions:

$$CWSI = \frac{(T_c - T_a)_m - (T_c - T_a)_{ll}}{(T_c - T_a)_{ul} - (T_c - T_a)_{ll}}$$

Where,

$(T_c - T_a)_m$: mean temperature difference

T_c: canopy temperature (^{0}C); T_a = air temperature (^{0}C)

Lower limit (ll): non-water-stressed baseline (lower baseline);

Upper limit (ul): non-transpiring upper baseline;

13.8 Development of Crop Coefficients

The single crop coefficient (Kc) will be developed in various treatments, including stress conditions, to quantify overall crop water use by relating crop evapotranspiration (ET_c) to reference evapotranspiration (ET_o). The Kc values will be determined for different crop growth stages to capture variations in water use throughout the crop cycle.

The approach used to estimate under varying stress levels and across different crop growth stages. This method enables detailed assessment of ETc under stress conditions, providing improved understanding of crop water use dynamics.

13.9 Stress Analysis

Water stress will be analyzed using soil moisture status and canopy temperature as key indicators, and appropriate stress-based irrigation scheduling strategies will be formulated water management.

13.10 Techno-Economic Analysis

The economic feasibility treatments will be evaluated through cost-benefit analysis, , and productivity assessment. Based on the findings, practical recommendations will be formulated for efficient and effective implementation of irrigation management practices under stress conditions.

13.11 Statistical Analysis

The experimental data will Design (FCRD) under the large plot technique. Analysis of variance (ANOVA) will be performed methods (drip and flood) and irrigation stress levels (full irrigation, 20% deficit, and 40% deficit), as well as their interactions on growth parameters, yield attributes, and crop coefficients. The will be tested at appropriate probability levels, and suitable tests will be applied for mean comparison.

14. References

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